(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 045 212 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
18.10.2000 Bulletin 2000/42

(51) Int. Cl.^{7}: **F25B 9/10**

(21) Application number: **00302727.3**

(22) Date of filing: **31.03.2000**

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **16.04.1999 US 292028**

(71) Applicant: **Raytheon Company**
El Segundo, California 90245 (US)

(72) Inventors:
- **Price, Kenneth D.**
  Long Beach, California 90807 (US)
- **Kirkconnel, Carl S.**
  Huntington Beach, California 92648 (US)
- **Neville, stephen C.**
  El Segundo, California 90245 (US)

(74) Representative:
Jackson, Richard Eric
Carpmaels & Ransford,
43 Bloomsbury Square
London WC1A 2RA (GB)

(54) Single-fluid stirling/pulse tube hybrid expander

(57) A hybrid two stage expander (10) having a first stage Stirling expander (20) coupled to a second stage pulse tube expander (30). Both stages are pneumatically driven by a common reciprocating compressor in a typical application). The first stage Stirling expander provides high thermodynamic efficiency which removes a majority of the heat load from gas within the cryocooler. The second stage pulse tube expander provides additional refrigeration capacity and improved power efficiency with little additional manufacturing complexity since it has no moving parts.

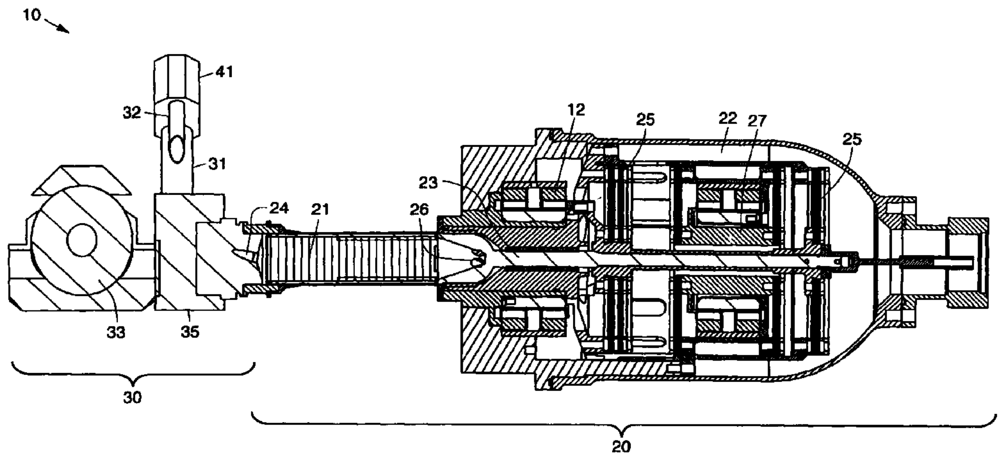

Fig. 1

Printed by Xerox (UK) Business Services
2.16.7 (HRS)/3.6

Description

BACKGROUND

[0001] The present invention relates generally to cryocoolers, and more particularly, to a two stage cryocooler having a hybrid configuration employing a Stirling first stage expander and a pulse tube second stage expander.

[0002] Low temperature refrigeration needs can often be met more efficiently with multi-stage refrigerators than with traditional single stage devices. For applications requiring closed-cycle refrigeration where multiple stages have been deemed advantageous, previous designs have typically implemented two or more expander stages of the same type. Examples of these expanders include those of the Stirling, Gifford-McMahon, pulse tube, and Joule-Thomson designs.

[0003] It would therefore be an advantage to have an improved cryocooler that improves upon conventional single and multi-stage designs. Accordingly, it is an objective of the present invention to provide for a two stage cryocooler having a hybrid configuration that uses a Stirling first stage expander and a pulse tube second stage expander.

SUMMARY OF THE INVENTION

[0004] To meet the above and other objectives, the present invention provides for a two stage expander having a hybrid configuration that combines a first stage Stirling expander with a second stage pulse tube expander. Both stages are pneumatically driven by a common reciprocating compressor or motor. The two stage cryocooler is designed for long, highly reliable life and is sufficiently small and light weight to permit its use in spacecraft applications.

[0005] The use of the first stage Stirling expander provides high thermodynamic efficiency in that it removes a majority of the heat load from gas within the cryocooler. The use of the second stage pulse tube expander provides additional refrigeration capacity and improved power efficiency with little additional manufacturing complexity due to the simplicity of the pulse tube expander, which has no moving parts. One of the major refrigeration losses in a traditional single-stage pulse tube expander, regenerator pressure drop, is relatively small in the present hybrid two stage cryocooler since the pulse tube regenerator operates at a reduced temperature (higher density yields lower gas velocity, which results in a lower pressure drop).

[0006] The use of the second stage pulse tube expander enables the incorporation of a flow-through heat exchanger at an interface between first and second stage expanders. This feature significantly improves first stage efficiency (relative to conventional single stage Stirling expanders) by virtue of the improved heat transfer coefficient at the thermal interface between the first and second stage expanders. Use of the first stage Stirling expander also reduces the total dead volume of the hybrid cryocooler compared to a pulse tube cooler (either one or two stage cooler having equivalent thermodynamic power). This reduces mass flow requirements, which in turn reduces the swept volume requirements of the compressor. This enables refrigeration to be accomplished with a smaller compressor.

[0007] The present invention may be adapted for use with cryogenic refrigerators used in military and commercial applications where the application demands high efficiency refrigeration at one or two temperatures, small size, low weight, long life, high reliability, and cost effective producibility. The primary intended use for the present invention is in space-based infrared sensors for civil and defense applications.

[0008] The present invention improves upon or displaces existing conventional cryocooler expanders including single and multi-stage Stirling expanders and single and multi-stage pulse tube expanders. The present hybrid expander achieves better performance at the same or lower manufacturing cost than either Stirling or pulse tube technology can deliver separately.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The various features and advantages of the present invention may be more readily understood with reference to the following detailed description taken in conjunction with the accompanying drawing, wherein like reference numerals designate like structural elements, and in which:

> Figs. 1-4 illustrate several cross sectional views of an exemplary hybrid two stage expander in accordance with the principles of the present invention.

DETAILED DESCRIPTION

[0010] Referring to the drawing figures, Figs. 1-4 illustrate cross sectional views of an exemplary hybrid two stage expander 10 in accordance with the principles of the present invention. The exemplary hybrid two stage expander 10 comprises first and second stages 20, 30. The first stage 20 comprises a Stirling expander 20 and the second stage 30 comprises a pulse tube expander 30.

[0011] The first stage Stirling expander 20 of the exemplary hybrid two stage cryocooler 10 comprises a flexure mounted Stirling expander 20. The Stirling expander 20 has a plenum 22 and a cold head comprising a thin walled cold cylinder, an expander inlet 26 disposed at a fore end of the plenum 22, a moveable displacer 23 or piston 23 disposed within the plenum 22, and a first stage regenerator 21 and heat exchanger 24.

[0012] The displacer 23 is suspended on fore and aft flexures 25. The displacer 23 is controlled and moved by means of a motor 12 located at a fore end of the plenum 22. A flexure suspended balancer 27 may be used to provide internal reaction against the inertia of the moving displacer 23.

[0013] The second stage pulse tube expander 30 comprises a second stage regenerator 31 or regenerative heat exchanger 31, a pulse tube 32, and a surge volume 33. The pulse tube 32 is coupled at one end to a second stage thermal interface 41. The second stage thermal interface 41 has a first end cap 42 that seals the pulse tube gas column 32, a second end cap 43 that seals the second stage regenerator 31 or regenerative heat exchanger 31. A second stage heat exchanger 44 is provided in the second stage thermal interface 41 that is coupled between the pulse tube 32 and the second stage regenerator 31.

[0014] A flow-through heat exchanger 34 is disposed at a thermal interface 35 between first stage Stirling expander 20 and the second stage pulse tube expander 30. The flow-through heat exchanger 34 includes a pulse tube inlet heat exchanger 51 and a pulse tube outlet heat exchanger 52. A third end cap 53 seals the end of the pulse tube gas column 32 in the flow-through heat exchanger 34. A port 54 is disposed in the flow-through heat exchanger 34 that is coupled to the surge volume 33 and provides a phase angle control orifice.

[0015] In the hybrid two stage expander 10, a gas such as helium, for example, flows into the expander inlet 26 and into the first stage regenerator 21 and heat exchanger 24. Gas flowing into the cold volume within the first stage Stirling expander 20 is regenerated by the first stage regenerator 21 and heat exchanger 24. A portion of the gas remains in the first stage expansion volume of the first stage regenerator 21. Progressively smaller portions of the gas continue to the second stage regenerator 31, the pulse tube 32, and the surge volume 33. Gas return flow follows the same path in reverse.

[0016] A significant advantage of the hybrid two stage expander 10, compared with other multistage expanders, is the ease of shifting refrigerating power between the two stages 20, 30. This is accomplished by varying the stroke and/or phase angle of the displacer 23 in the Stirling first stage expander 20 and by means of the port 54, which alters mass flow distribution into the surge volume 33. This additional degree of control enables performance optimization at any operating point, including on orbit in the actual thermal environment of a spacecraft, for example. This feature provides for power savings when using the hybrid two stage expander 10.

[0017] The first stage Stirling expander 20 has high thermodynamic efficiency when removing the majority of the heat load from gas within the expander 10. The second stage pulse tube expander 30 provides additional refrigeration capacity and improved power efficiency. The second stage pulse tube expander 30 adds little additional manufacturing complexity because of its simplicity, in that it has no moving parts.

[0018] The flow-through heat exchanger 34 at the interface 35 between first and second stage expanders 20, 30 significantly improves first stage efficiency (relative to conventional single stage Stirling expanders) by virtue of the improved heat transfer coefficient at the thermal interface therebetween. The Stirling expander 20 reduces the total dead volume of the hybrid expander 10 compared to a conventional one or two stage pulse tube cooler having an equivalent thermodynamic power. The Stirling expander 20 thus reduces mass flow requirements, which reduces the swept volume of the compressor and enables refrigeration to be accomplished with a smaller compressor.

[0019] The regenerator pressure drop is relatively small in the hybrid two stage expander 10 because the pulse tube regenerator 31 operates at a reduced temperature. The gas thus has a higher density and produces a lower gas velocity, which results in a lower pressure drop.

[0020] The hybrid two stage expander 10 may be used in cryogenic refrigerators adapted for military and commercial applications where high efficiency refrigeration is required at one or two temperatures. The hybrid two stage expander 10 is also well suited for use in applications requiring small size, low weight, long life, high reliability, and cost effective producibility. The hybrid two stage expander 10 is particularly well suited for use in civil and defense space-based infrared sensors, such as those used in spacecraft infrared sensor systems, and the like.

[0021] Thus, an improved hybrid two stage expander has been disclosed. It is to be understood that the described embodiment is merely illustrative of some of the many specific embodiments which represent applications of the principles of the present invention. Clearly, numerous and other arrangements can be readily devised by those skilled in the art without departing from the scope of the invention.

Claims

1. A hybrid two stage expander (10) characterized by:

   a first stage Stirling expander (20); and
   a second stage pulse tube expander (30) thermally coupled to the first stage Stirling expander.

2. The expander (10) recited in Claim 1 wherein the first stage Stirling expander (20) is characterized by a flexure mounted Stirling expander (20).

3. The expander (10) recited in Claim 1 wherein the first stage Stirling expander (20) is characterized by:

   a plenum (22);

an expander inlet (26) disposed at one end of the plenum;

a displacer (23) disposed within the plenum; and

a first stage regenerator (21).

4. The expander (10) recited in Claim 3 wherein the displacer (23) is suspended on fore and aft flexures (25) separated by a rigid standoff (26).

5. The expander (10) recited in Claim 1 wherein the second stage pulse tube expander (30) is characterized by:

a second stage regenerator (31);

a pulse tube gas column (32) thermally coupled to the second stage regenerator; and

a surge volume (33) coupled to the pulse tube gas column.

6. The expander (10) recited in Claim 5 further characterized by:

a second stage thermal interface 41 coupled at one end to the pulse tube (32) that includes a first end cap 42 that seals the pulse tube gas column, a second end cap 43 that seals the second stage regenerator (31), a second stage heat exchanger coupled between the pulse tube gas column and the second stage regenerator.

7. The expander (10) recited in Claim 1 further characterized by:

a flow-through heat exchanger (34) disposed at a thermal interface (35) between first stage Stirling expander (20) and the second stage pulse tube expander (30).

8. The expander (10) recited in Claim 7 wherein the flow-through heat exchanger (34) is characterized by:

a pulse tube inlet heat exchanger 51;

a pulse tube outlet heat exchanger 52;

a port 54 coupled to the surge volume (33) that provides a phase angle control orifice.

9. The expander (10) recited in Claim 1 further characterized by a flexure suspended balancer (27) for providing internal reaction against the inertia of the displacer (23).

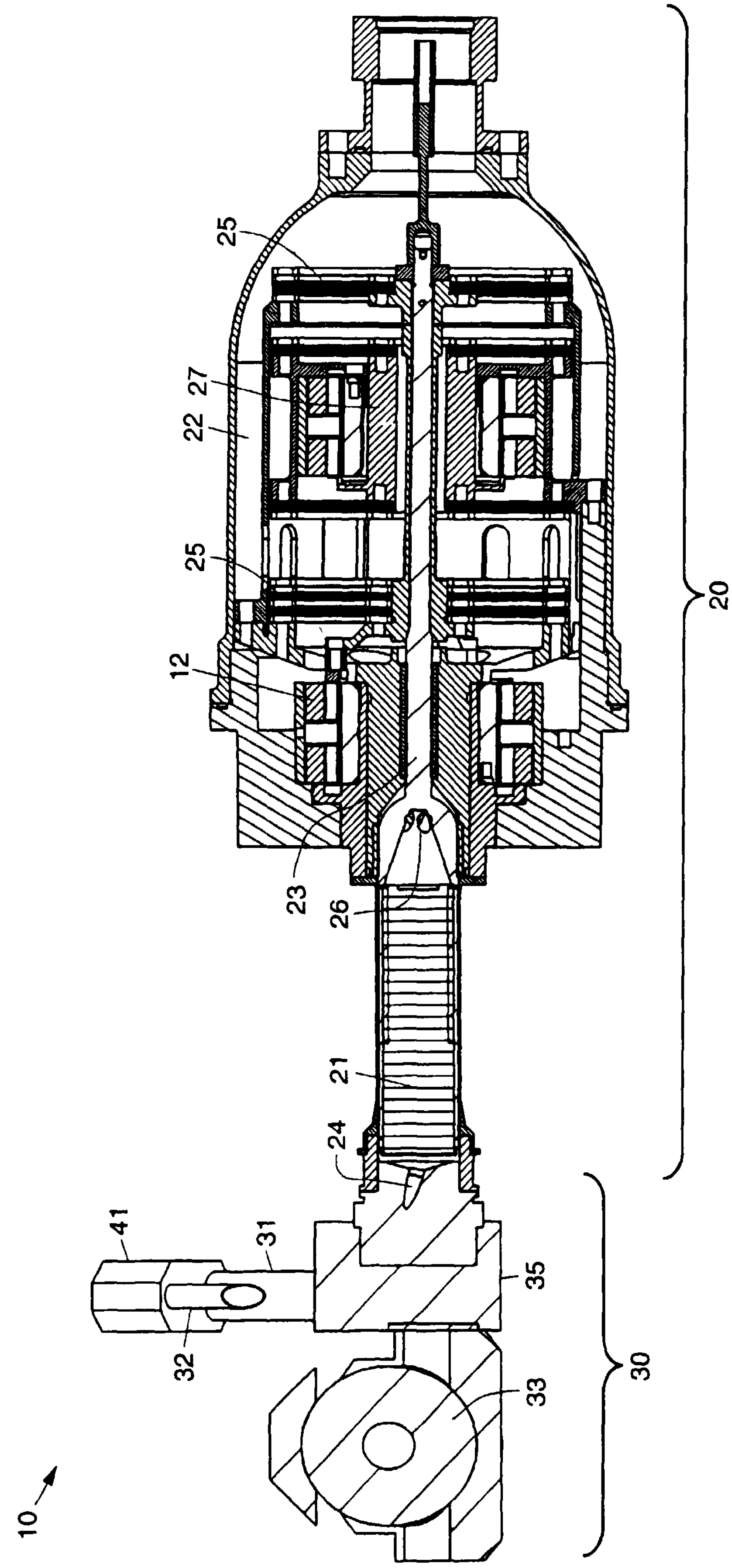

Fig. 1

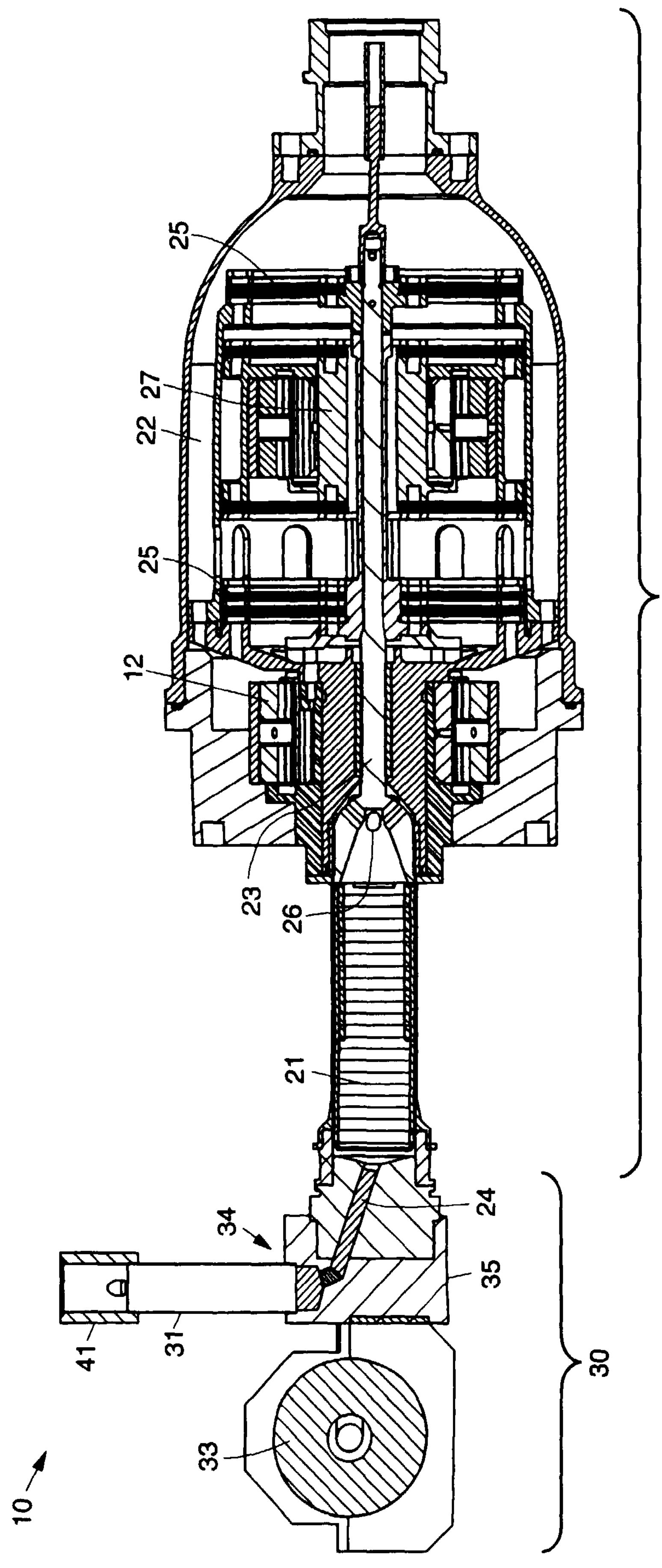

Fig. 2

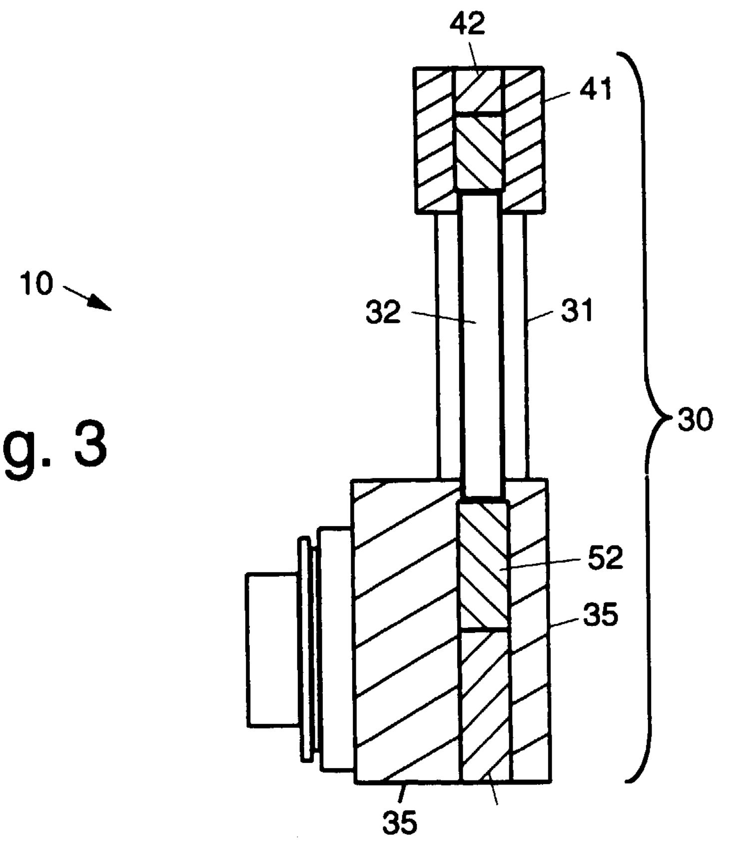

Fig. 3

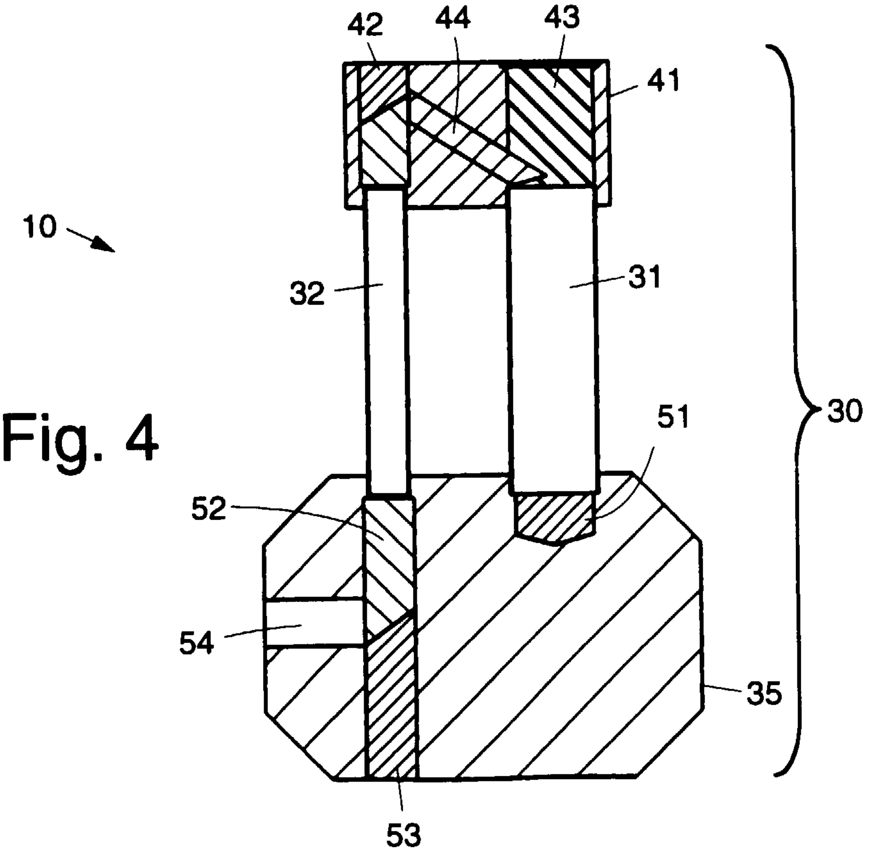

Fig. 4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 00 30 2727

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X Y A	US 5 711 157 A (CHANDRATILLEKE ROHANA ET AL) 27 January 1998 (1998-01-27) * column 8, line 62 - column 34, line 33; figures 5-22 *	1,3,5 2,4 7	F25B9/10
Y	US 5 647 217 A (PENSWICK LAURENCE B ET AL) 15 July 1997 (1997-07-15) * column 4, line 33 - column 12, line 9; figures 3-6 *	2,4	
X	US 5 642 623 A (HIRESAKI YU ET AL) 1 July 1997 (1997-07-01) * column 3, line 60 - column 8, line 67; figures 1-7 *	1,3,5	
X	DE 196 12 539 A (LEYBOLD VAKUUM GMBH) 2 October 1997 (1997-10-02) * column 2, line 30 - column 5, line 7; figures 2-4 *	1,3,5	**TECHNICAL FIELDS SEARCHED (Int.Cl.7)**
X A	US 5 647 218 A (KURIYAMA TORU ET AL) 15 July 1997 (1997-07-15) * column 6, line 21 - line 43; figure 4 * * column 7, line 23 - line 44; figure 6 *	1,3 5,7	F25B
X	PATENT ABSTRACTS OF JAPAN vol. 018, no. 611 (M-1708), 21 November 1994 (1994-11-21) & JP 06 229641 A (NAOJI ISSHIKI;OTHERS: 01), 19 August 1994 (1994-08-19) * abstract *	1	
A	EP 0 553 818 A (MITSUBISHI ELECTRIC CORP) 4 August 1993 (1993-08-04) * column 5, line 36 - column 10, line 39; figures 1-15 *	2,4	

-/--

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	7 June 2000	Boets, A

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 00 30 2727

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	US 5 107 683 A (CHAN CHUNG K ET AL) 28 April 1992 (1992-04-28)		
A	US 5 647 219 A (PRICE KENNETH D ET AL) 15 July 1997 (1997-07-15)		
A	US 5 735 127 A (LOKKEN ORRIN D ET AL) 7 April 1998 (1998-04-07)		
A	US 4 819 439 A (HIGHAM GRAHAM J) 11 April 1989 (1989-04-11)		

TECHNICAL FIELDS SEARCHED (Int.Cl.7)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	7 June 2000	Boets, A

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 00 30 2727

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

07-06-2000

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5711157 A	27-01-1998	JP 8313094 A	29-11-1996
		JP 8313095 A	29-11-1996
		JP 9036442 A	07-02-1997
		GB 2301426 A,B	04-12-1996
		GB 2318176 A,B	15-04-1998
US 5647217 A	15-07-1997	NONE	
US 5642623 A	01-07-1997	JP 8226719 A	03-09-1996
DE 19612539 A	02-10-1997	WO 9737174 A	09-10-1997
		EP 0890063 A	13-01-1999
US 5647218 A	15-07-1997	GB 2301174 A,B	27-11-1996
		JP 9033126 A	07-02-1997
JP 06229641 A	19-08-1994	JP 2719293 B	25-02-1998
EP 0553818 A	04-08-1993	DE 69300919 D	18-01-1996
		DE 69300919 T	01-08-1996
		US 5351490 A	04-10-1994
		JP 5288419 A	02-11-1993
US 5107683 A	28-04-1992	NONE	
US 5647219 A	15-07-1997	NONE	
US 5735127 A	07-04-1998	NONE	
US 4819439 A	11-04-1989	CA 1314719 A	23-03-1993
		WO 8903481 A	20-04-1989

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82